

## Durham Research Online

---

### Deposited in DRO:

20 April 2020

### Version of attached file:

Accepted Version

### Peer-review status of attached file:

Peer-reviewed

### Citation for published item:

Lahdelma, I. and Armitage, J. and Eerola, T. (2022) 'Affective priming with musical chords is influenced by pitch numerosity.', *Musicae scientiae*, 26 (1). pp. 208-217.

### Further information on publisher's website:

<https://doi.org/10.1177/1029864920911127>

### Publisher's copyright statement:

This article is distributed under the terms of the Creative Commons Attribution 4.0 License (<https://creativecommons.org/licenses/by/4.0/>) which permits any use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access page (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).

### Additional information:

## Use policy

---

The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a [link](#) is made to the metadata record in DRO
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the [full DRO policy](#) for further details.

Affective Priming With Musical Chords is Influenced by Pitch Numerosity

Imre Lahdelma<sup>1</sup>, James Armitage<sup>1</sup>, & Tuomas Eerola<sup>1</sup>

<sup>1</sup> Durham University, UK

Author Note

Author accepted manuscript: Lahdelma, I., Armitage, J., & Eerola, T. (2020). Affective Priming With Musical Chords is Influenced by Pitch Numerosity. *Musicae Scientiae*, <https://doi.org/10.1177/1029864920911127>

Correspondence concerning this article should be addressed to Imre Lahdelma, Palace Green, DH1 3RL, Durham, United Kingdom. E-mail: [imre.d.lahdelma@durham.ac.uk](mailto:imre.d.lahdelma@durham.ac.uk)

## Abstract

Previous studies using an affective priming paradigm have shown that valenced chords (e.g., consonant-positive; dissonant-negative) facilitate the evaluation of similarly valenced target words. The role of numerosity (the total number of pitches in a chord) and timbre have not yet been systematically investigated in previous priming studies using consonant/dissonant chords.

An empirical experiment was conducted where forty participants evaluated positive and negative target words with consonant/dissonant chords used as affective primes. Eight distinct chords (four consonant and four dissonant) were used as primes; the consonant and dissonant chords were equally divided to comprise either two (i.e., interval) or four (i.e., tetrad) pitches. The chords were played with two distinct timbres, the piano and the harmonium respectively, resulting in a total of 16 chords.

The results show that congruent chord-word pairings result in faster reaction times, and this finding is in line with previous research using consonant/dissonant chords as primes (Sollberger et al., 2003; Steinbeis & Koelsch, 2011). However, this effect was present only with tetrad chords, suggesting that numerosity influences affective priming done with chords. The role of timbre did not prove to be significant, nor the musical sophistication of the participants. Arguments are made on why higher pitch numerosity (resulting in acoustic complexity) in chords might influence the evaluation of valenced target words.

*Keywords:* affective priming, chord, consonance, dissonance, interval, numerosity, roughness

## Affective Priming With Musical Chords is Influenced by Pitch Numerosity

**Introduction**

The contrast between consonance and dissonance is a crucial feature of Western music. While the exact acoustic and cultural components of consonance and their order of importance is notoriously contentious (see e.g., Harrison & Pearce, 2019), there is agreement over the notion that consonant typically means *harmonious*, *agreeable*, and *stable*, while dissonant, in contrast, means *disagreeable*, *unpleasant*, and *in need of resolution* (see Tramo, Cariani, Delgutte, & Braida, 2001). The current study is concerned with the perception of isolated vertical intervals (two concurrent pitches) and chords (three or more concurrent pitches). The term “chord” will be used as a broad category comprising both intervals and actual chords for ease of communication, as this is a common procedure in studies dealing with the perception of simultaneous pitch combinations (see e.g., Bowling, Purves, & Gill, 2018). On an affective level, many self-report studies have demonstrated that dissonant chords are perceived as more negative and unpleasant than their consonant counterparts (see e.g., Arthurs, Beeston, & Timmers, 2018; Costa, Ricci Bitti, & Bonfiglioli, 2000; Maher, 1980). Zentner & Kagan (1996) suggest that the preference for consonance over dissonance is present already in infants, implying that humans might at least to some extent be biologically prepared to prefer consonance over harsh dissonance.

As a research method, the affective priming paradigm consists of two stimuli (the prime and the target) presented in succession. Participants then evaluate the target stimulus according to a binary division such as “positive” and “negative”. The experimental manipulation is whether or not the prime and target share an affective property such as valence. Although scholars disagree on the exact mechanism responsible (for a review, see e.g., Herring et al., 2013), target stimuli are typically evaluated faster when preceded by a prime of the same affective category compared to one of the opposite category. Affective

priming paradigms have consistently been found to be a robust measure of attitudes to prime stimuli (see Fazio, 2001) and avoid many of the limitations of self-report measures as outlined by for example Zentner & Eerola (2010).

Only a handful of affective priming studies have investigated the effect of consonance/dissonance on the evaluation of valenced target words. Sollberger, Rebe, & Eckstein (2003) and Steinbeis & Koelsch (2011) found that participants evaluated target words faster if the words were preceded by a similarly valenced chord (e.g., consonant-positive) compared to affectively incongruent chord-word pairs (e.g., dissonant-positive), and this finding was independent of musical training. Costa (2013) later tested the chord stimuli of Sollberger et al. (2003) using emotional pictures instead of words as the targets, and curiously in this setting the priming with consonant/dissonant chords was not effective.

These previous studies using consonant/dissonant chords as primes have not yet been systematic in identifying what aspects of the chords lead to priming effects. None of them have directly explored the role of *numerosity* (the total number of pitches in a chord) and timbre in consonant/dissonant chords used as affective primes. It has been theorised that numerosity affects the perceived consonance of chords; the addition of pitches to a chord typically increases its acoustic *roughness* (Bowling & Purves, 2015), an acoustic component which is seen as prevalent in dissonant, but not in consonant musical chords (see e.g., Hutchinson & Knopoff, 1979; Plomp & Levelt, 1965). This would imply that dissonant chords with higher numerosity and hence higher roughness could be more congruent with negative target words compared to dissonant but less rough intervals. Also, on a cognitive level it has been suggested that stimuli that are easier to process result in more positive affective reactions (e.g., Winkielman & Cacioppo, 2001); according to this logic a consonant interval consisting of only two pitches might result in an easier processing than a consonant tetrad consisting of four pitches, ensuing higher congruency with positive target words. In

the previous affective priming studies using consonant/dissonant chords Sollberger et al. (2003) tested three- and four-pitch chords for dissonance, but only three-pitch chords for consonance. The results showed no difference in congruency effects according to pitch numerosity. Steinbeis & Koelsch (2011), in turn, used exclusively four-pitch chords for both consonance and dissonance. Costa (2013) later used the same three-pitch chords as Sollberger et al. (2003). Consequently, two-pitch chords (intervals) have never been tested in an affective priming setting to investigate whether chord numerosity plays a role in the evaluation of valenced target words. Also, previous affective priming studies with consonant/dissonant chords have used exclusively the piano timbre, and this can be seen as a possible limitation. Timbre has been shown to strongly affect the perception of single chords in self-report studies (see Arthurs et al., 2018; Lahdelma & Eerola, 2016b) where the piano timbre was rated more positive than for example the strings or the organ. Moreover, the timbre of isolated musical instrument sounds has been demonstrated to convey distinct emotions in an affective priming setting (Liu, Xu, Alter, & Tuomainen, 2018).

## Methods

### Participants

The participants for the experiment were recruited through *Prolific Academic* (<https://prolific.ac>), an online crowdsourcing platform targeted especially for research purposes. Previous research suggests that Prolific participants consistently complete questionnaires carefully and the platform has high reliability (see Palan & Schitter, 2018; Peer, Brandimarte, Samat, & Acquisti, 2017). Written informed consent was obtained from all participants before the start of the experiment, and the study was approved by the institutional ethics committee.

## Materials

The stimuli were chosen on the basis of an empirical rank ordering of consonance/dissonance ratings of intervals and tetrads conducted by Bowling et al. (2018); the two most consonant/dissonant intervals and tetrads were chosen to represent each category (e.g., consonant interval), resulting in a total of eight distinct chords (Table 1). As per the procedure by Bowling et al. (2018), the fundamental frequencies ( $f_0$ ) of the pitches in each chord were adjusted so that the mean  $f_0$  of all pitches was 263 Hz (middle C). The chords were played with both the piano and the harmonium timbre, resulting in 16 chords altogether. All chords were played in equal temperament. The piano timbre was chosen as it is a common and highly familiar instrument; also, it has been used in the three previous affective priming studies applying consonant/dissonant chords. The harmonium was chosen to represent a categorically different and less familiar timbre compared to the piano, as it has a slow attack and a sustained sound as opposed to the piano’s sharp attack and fast decay. No a priori hypotheses was put forward with regard to their possible valence differences.

Consonance	Numerosity	Name	Integer Notation
Consonant	Interval 1	Perfect fifth (P5)	{0 7}
Consonant	Interval 2	Perfect octave (P8)	{0 12}
Dissonant	Interval 1	Minor second (m2)	{0 1}
Dissonant	Interval 2	Major seventh (M7)	{0 11}
Consonant	Tetrad 1	Major chord (2nd inversion w/doubled 5th)	{0 5 9 12}
Consonant	Tetrad 2	Major chord (root position + octave)	{0 4 7 12}
Dissonant	Tetrad 1	Chromatic cluster	{0 1 2 12}
Dissonant	Tetrad 2	Chromatic cluster	{0 1 2 11}

Table 1: The chord stimuli.

The chords were exactly 800 ms in length including a 75 ms fadeout. The chords were generated with *Ableton Live 9* (a music sequencer software). The piano chords were created using the *Synthogy Ivory Grand Pianos II* plug-in with *Steinway D Concert Grand* as the applied sound font. The harmonium chords were created with *Noiiz Player* (a sampler instrument plug-in) using the *Harmonium* sound library with *Harmonium II* as the applied sound font. No reverb was used, and a fixed velocity was applied. All stimuli were normalised to -3db with *Adobe Audition CC 2019* (a digital audio workstation) in order to control for any amplitude differences due to numerosity and timbre dissimilarities. The chords were rendered as 44.1 kHz, 32 bits per sample waveform audio files and were then converted to constant bit rate 320kbps high quality stereo mp3 files for compatibility with the survey design used in the experiment (see Procedure). The stimuli can be found online at <https://anonymised.for.review>. The positive/negative target words were taken from Warriner, Kuperman, & Brysbaert (2013). Altogether 16 words were chosen according to valence (positive vs. negative). The words were all similar in length, consisting of two syllables, with the exception of one word (*rest*) consisting of one syllable. The positive words were *climax*, *lively*, *gentle*, *rest*, *excite*, *payday*, *comfy*, *relax*; the negative words were *rabid*, *hijack*, *coma*, *saggy*, *arrest*, *fatal*, *dismal*, and *morgue*.

**Numerosity and Roughness.** As pitch numerosity is closely linked to the question of acoustic roughness (see Bowling & Purves, 2015), roughness calculations were conducted on the chord stimuli. Figure 1 shows the theoretical roughness values of the eight different chords (collapsed across timbre) assessed with the model of Hutchinson & Knopoff (1978); this model has recently been demonstrated to be the most reliable predictor of consonance/dissonance ratings among several roughness models (see Harrison & Pearce, 2019). As can be seen from Figure 1, both the consonant and dissonant tetrads are more rough than their interval counterparts, and this difference is especially prominent with the dissonant chords.



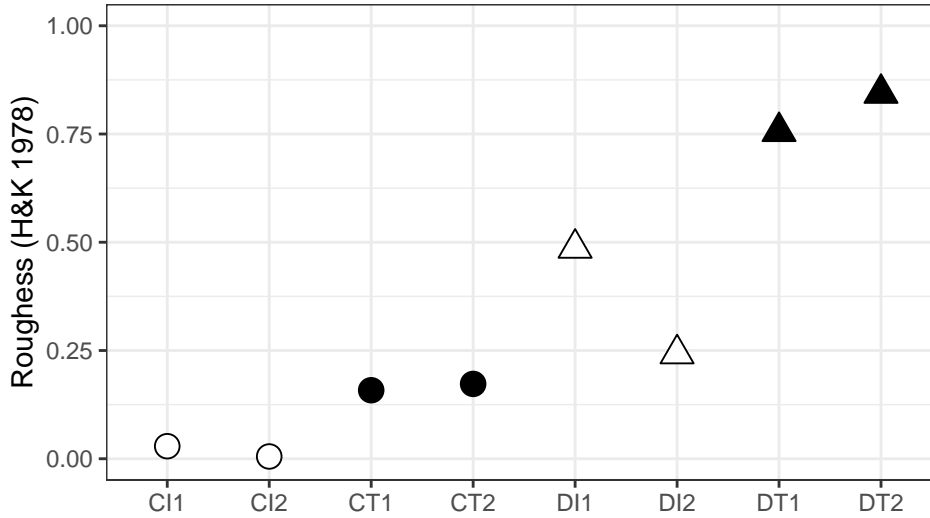


Figure 1: Theoretical roughness values across the eight chords (C=Consonant, D=Dissonant, I=Interval, T=Tetrad, see Table 1 for full details).

## Procedure

The experiment was programmed and conducted on PsyToolkit, a web-based service designed for setting up, running, and analysing online questionnaires and reaction-time experiments (see Stoet, 2017). The web-based reaction time approach has been validated to generate data that is comparable to lab-based data (Hilbig, 2016). Before the experimental task, participants were asked to provide information about their demographic background (age, gender, and musical sophistication). For the priming task, participants were presented with a series of words, which had to be classified as positive (by pressing the “m” key) or negative (by pressing the “z”) key. Each word was preceded by a chord. The task comprised a ten-item practice block followed by an experimental block of 256 items (16 primes  $\times$  16 targets) presented in a random order. Participants received feedback during the practice block to indicate whether or not their responses were correct; no feedback was provided during the experimental block. For each item, the screen initially contained a fixation cross

for 500 ms; at 500 ms, the fixation cross disappeared and the auditory prime (duration 800 ms) sounded. 200 ms after the onset of the auditory prime, the target word appeared in the centre of the screen and remained for 2000 ms, during which time participants were able to respond. Responses slower than 2000 ms were classed as “timeouts”. Following the experiment, participants were presented with an online debriefing screen and issued with an anonymous participant code.

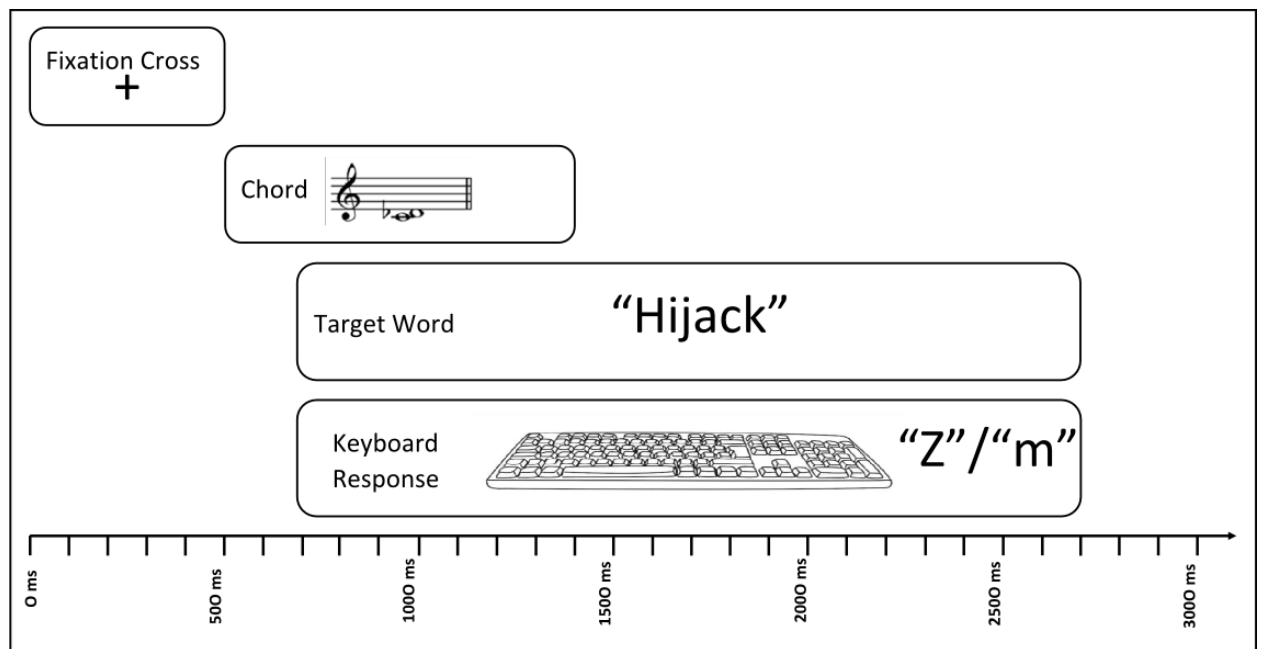


Figure 2: Schematic diagram of the experiment procedure.

## Results

### Reaction Time

**Data Pre-Treatment.** Reaction times shorter than 250 ms were deleted (Hermans, De Houwer, & Eelen, 2001). To calculate upper outliers, each participant's data was fitted to an exponentially modified Gaussian (ExGaussian) distribution (Ratcliff, 1993); responses slower than the 95th percentile of this distribution were deleted as were incorrect responses. Finally, as is common practice (Whelan, 2008), reaction times were log transformed prior to analysis.

**Analysis of Reaction Time Data.** The data were subjected to 2 (consonance-dissonance)  $\times$  2 (timbre)  $\times$  2 (numerosity) repeated-measures linear mixed effects anova. Several authors suggest avoiding standardised effect sizes with linear mixed effect models, advocating instead for simple effect sizes, which are reported here (Baguley, 2009; Rights & Sterba, 2019; Wilkinson, 1999). The analysis revealed no significant main effects of consonance-dissonance, timbre, or numerosity. However, as predicted, there was a significant interaction of Consonance  $\times$  Target Valence,  $F(1,272) = 12.97$ ,  $p < .001$ , revealing clear congruency effects. Post hoc tests confirmed that reaction times to positive words were faster when preceded by consonant chords (mean RT = 586 ms,  $SD = 117$  ms) than by dissonant chords (mean RT = 594 ms,  $SD = 112$  ms),  $t(34) = 2.28$ ,  $p = .03$ ; similarly, reaction times to negative words were marginally faster when preceded by dissonant chords (mean RT = 588 ms,  $SD = 116$  ms) than by consonant chords (mean RT = 595,  $SD = 113$  ms),  $t(34) = 1.87$ ,  $p = .06$ . This interaction was further qualified by a significant three-way interaction Numerosity  $\times$  Consonance  $\times$  Target Valence,  $F(1,272) = 4.42$ ,  $p = .03$ . Post hoc tests indicated that the interaction Consonance  $\times$  Target Valence was present in the case of tetrads,  $F(1,68) = 11.44$ ,  $p = .001$ , but that this interaction was not present in the case of intervals,  $F(1,68) = 0.88$ ,  $p = .35$ . Considering tetrads only, positive targets were evaluated significantly more quickly following a consonant prime compared to a dissonant prime,  $t(136) = 2.58$ ,  $p = .01$ , difference in means = 15 ms; the effect was marginal in the case of negative targets - there was a non-significant trend for targets to be evaluated more quickly following a dissonant prime compared to a consonant prime,  $t(136) = 1.78$ ,  $p = .08$ .

difference in means = 11 ms). These differences were not present in the case of intervals, where the difference in mean reaction times for positive targets was 0.4 ms and the mean RT for negative targets was 4 ms. Figure 3 demonstrates graphically the presence of the effect in the case of tetrads, but not in intervals. The interaction Timbre  $\times$  Target Valence did not prove to be significant. All other two, three, and four-way interactions proved to be non-significant. In order to test for group differences between musicians and non-musicians, we calculated a priming index, defined as difference in mean response times for incongruent minus congruent conditions (see e.g. Blair et al., 2006). There was no significant difference in priming index between musicians and non-musicians,  $t(18.2) = 0.37$ ,  $p > .05$  (see Delacre, Lakens, & Leys, 2017 for Welch's  $t$ -test for groups with unequal variances).

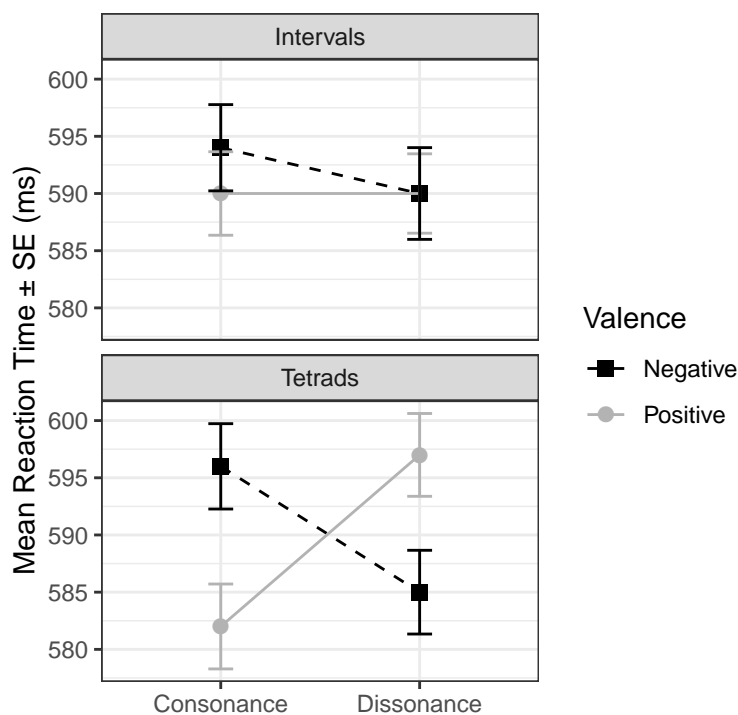


Figure 3: Reaction time across Consonance and Negative/Positive primes.

## Accuracy Rates

Results for accuracy rates (AR) broadly mirrored those for RT. There was a significant main effect of target valence  $F(1,272) = 8.97, p = .003$ . Post hoc tests suggested that negative targets were evaluated more accurately (mean AR = 95.3%) than positive targets (mean AR = 93.4%),  $t(34) = 3.53, p = .001$ . All other main effects were non-significant. The two-way interaction Consonance  $\times$  Target Valence proved marginally significant,  $F(1,272) = 3.26, p = .07$ . Post hoc testing indicated that Positive targets were evaluated marginally more accurately following a consonant prime (90.3%) compared to a dissonant prime (88.9%)  $t(34) = 1.7, p = .09$ ; there was no significant difference in AR to negative targets when following consonant (80.7%) vs. negative primes (81.5%). Furthermore, the three-way interaction Numerosity  $\times$  Consonance  $\times$  Target Valence was highly significant,  $F(1,272) = 9.99, p = .002$ . As with RT, the interaction Consonance  $\times$  Target Valence was present in the case of tetrads,  $F(1,68) = 8.71, p = .004$ , but not in the case of intervals,  $F(1,68) = 0.38, p = .58$ . Considering tetrads alone, ARs for positive words were significantly higher when preceded by consonant tetrads (mean AR = 90.5%) compared to dissonant tetrads (mean AR = 79.7%),  $t(34) = 2.12, p = .04$ ; however, negative words were classified more accurately when preceded by consonant tetrads (mean AR = 87.7%) than dissonant tetrads (mean AR = 82.5%),  $t(34) = 2.77, p = .048$ . No such interaction was present in the case of intervals. Rather than presenting congruency effects as is the case with RT, the effect in AR seems to be to reduce the influence of an over-riding main effect of Target Valence,  $F(1,272) = 195, p < .001$ : post hoc testing suggested that positive words (AR = 89.6%) were classified more accurately than negative words (AR = 81.1%),  $t(34) = 7.5, p < .001$ .

## Discussion

The current study has demonstrated for the first time that pitch numerosity plays a role in consonant/dissonant chords when used as primes for valenced target words. This

finding has a plausible explanation in the case of dissonant chords: it has been suggested that the addition of pitches to a chord typically increases its acoustic roughness (Bowling & Purves, 2015) which results in more perceived dissonance. It is likely that this high amount of roughness makes the dissonant tetrads effective primes for valenced target words.

Interestingly, numerosity plays an equally important role in the case of consonant chords where also only the tetrads were effective primes: consonant chords with a smaller number of pitches (intervals) did not create more congruency with positive words (cf. Winkielman & Cacioppo, 2001) even though they contain less roughness than the consonant tetrads. As the consonant intervals represented pure consonance (the perfect fifth, the perfect octave) they were possibly less loaded in terms of positive valence than the major chord tetrads: major chords have been demonstrated to contain a high amount of positive valence in self-report studies (see e.g., Lahdelma & Eerola, 2016a). However, in the previous affective priming studies with consonant/dissonant chords Sollberger et al. (2003) used a perfect fifth + octave sonority as the consonant chord (three pitches) which was not a major chord, while Steinbeis & Koelsch (2011) used major chords with pitch doublings (four pitches). Both of these studies demonstrated a congruency effect for consonant chords presented with positive target words implying that it is not necessarily the major chord driving this congruency effect.

The finding that intervals are not effective primes compared to tetrads is striking in the light that certain intervals have been demonstrated to convey distinct affective connotations to Western listeners in self-report studies (see e.g., Oelmann & Laeng, 2009; Krantz, Merker, & Madison, 2004). The dissonant intervals used in the current experiment (the minor second and the major seventh) have consistently been demonstrated to be among the most dissonant intervals (see e.g., Malmberg, 1918; Hutchinson & Knopoff, 1979; Kameoka & Kuriyagawa, 1969). The dissonance in these intervals is mirrored in their perceived affective connotations on the basis of self-report studies: Maher (1980) found that the minor second interval was perceived as more *unstable*, *displeasing*, and *restless* when compared to the consonant perfect fifth and the perfect octave. Interestingly, in Maher's

study the participants failed to discriminate any of the 14 presented intervals (all the intervals ranging from the unison to the octave + the minor ninth) on the *How-do-you-feel* scale. Maher (1980) concludes that the various intervals do not give rise to differential degrees of felt activation and liveliness, a notion that is line with the current experiment's findings that intervals are not as effective primes as tetrads. On the basis of the current findings, intervals are possibly not acoustically complex enough to elicit congruency effects in a reaction time setting when used as primes, at least when in a context of being presented alongside more complex chords (in this case, tetrads).

Based on these results, more research is suggested on specifically the effect of culturally loaded intervals in terms of valence (e.g., the positive major third and the negative minor third and the tritone) to see if intervals by themselves can act as affective primes due to their conventional affective connotations despite lesser acoustic complexity. Although the role of timbre proved non-significant in the current study, timbre offers multiple options (e.g., harmonics, envelope, spectral shape) that might contribute to affective priming done with chords. Hence, more diverse timbres should be explored to see if they interact with consonant/dissonant chords when used as primes in an affective priming paradigm.

## References

- Arthurs, Y., Beeston, A. V., & Timmers, R. (2018). Perception of isolated chords: Examining frequency of occurrence, instrumental timbre, acoustic descriptors and musical training. *Psychology of Music*, 46(5), 662–681.
- Baguley, T. (2009). Standardized or simple effect size: What should be reported? *British Journal of Psychology*, 100(3), 603–617.
- Blair, K., Richell, R., Mitchell, D., Leonard, A., Morton, J., & Blair, R. (2006). They know the words, but not the music: Affective and semantic priming in individuals with psychopathy. *Biological Psychology*, 73(2), 114–123.
- Bowling, D. L., & Purves, D. (2015). A biological rationale for musical consonance. *Proceedings of the National Academy of Sciences*, 112(36), 11155–11160.
- Bowling, D. L., Purves, D., & Gill, K. Z. (2018). Vocal similarity predicts the relative attraction of musical chords. *Proceedings of the National Academy of Sciences*, 115(1), 216–221.
- Costa, M. (2013). Effects of mode, consonance, and register in visual and word-evaluation affective priming experiments. *Psychology of Music*, 41(6), 713–728.
- Costa, M., Ricci Bitti, P. E., & Bonfiglioli, L. (2000). Psychological connotations of harmonic musical intervals. *Psychology of Music*, 28(1), 4–22.
- Delacre, M., Lakens, D., & Leys, C. (2017). Why psychologists should by default use Welch's t-test instead of Student's t-test with unequal group sizes. *International Review of Social Psychology*, 30, 92–101.
- Fazio, R. H. (2001). On the automatic activation of associated evaluations: An overview.



*Cognition & Emotion*, 15(2), 115–141.

Harrison, P., & Pearce, M. (2019). Instantaneous consonance in the perception and composition of Western music. *PsyArXiv Preprints*. Retrieved from <https://doi.org/10.31234/osf.io/6jsug>

Hermans, D., De Houwer, J., & Eelen, P. (2001). A time course analysis of the affective priming effect. *Cognition & Emotion*, 15(2), 143–165.

Herring, D. R., White, K. R., Jabeen, L. N., Hinojos, M., Terrazas, G., Reyes, S. M., ... Crites Jr, S. L. (2013). On the automatic activation of attitudes: A quarter century of evaluative priming research. *Psychological Bulletin*, 139(5), 1062–1089.

Hilbig, B. E. (2016). Reaction time effects in lab-versus web-based research: Experimental evidence. *Behavior Research Methods*, 48(4), 1718–1724.

Hutchinson, W., & Knopoff, L. (1978). The acoustic component of Western consonance. *Interface*, 7(1), 1–29.

Hutchinson, W., & Knopoff, L. (1979). The significance of the acoustic component of consonance in Western triads. *Journal of Musicological Research*, 3(1-2), 5–22.

Kameoka, A., & Kuriyagawa, M. (1969). Consonance theory part I: Consonance of dyads. *The Journal of the Acoustical Society of America*, 45(6), 1451–1459.

Krantz, G., Merker, B., & Madison, G. (2004). Subjective reactions to musical intervals assessed by rating scales. In *Proceedings of The Eighth International Conference on Music Perception and Cognition* (Vol. 5). Evanston, IL: Northwestern University.

Lahdelma, I., & Eerola, T. (2016a). Mild dissonance preferred over consonance in single chord perception. *I-Perception*, 7(3), 1–21.

- Lahdelma, I., & Eerola, T. (2016b). Single chords convey distinct emotional qualities to both naive and expert listeners. *Psychology of Music*, 44(1), 37–54.
- Liu, X., Xu, Y., Alter, K., & Tuomainen, J. (2018). Emotional connotations of musical instrument timbre in comparison with emotional speech prosody: Evidence from acoustics and event-related potentials. *Frontiers in Psychology*, 9, 737.
- Maher, T. F. (1980). A rigorous test of the proposition that musical intervals have different psychological effects. *The American Journal of Psychology*, 93, 309–327.
- Malmberg, C. F. (1918). The perception of consonance and dissonance. *Psychological Monographs*, 25(2), 93–133.
- Oelmann, H., & Laeng, B. (2009). The emotional meaning of harmonic intervals. *Cognitive Processing*, 10(2), 113–131.
- Palan, S., & Schitter, C. (2018). Prolific.ac—a subject pool for online experiments. *Journal of Behavioral and Experimental Finance*, 17, 22–27.
- Peer, E., Brandimarte, L., Samat, S., & Acquisti, A. (2017). Beyond the Turk: Alternative platforms for crowdsourcing behavioral research. *Journal of Experimental Social Psychology*, 70, 153–163.
- Plomp, R., & Levelt, W. J. M. (1965). Tonal consonance and critical bandwidth. *The Journal of the Acoustical Society of America*, 38(4), 548–560.
- Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin*, 114(3), 510–532.
- Rights, J. D., & Sterba, S. K. (2019). Quantifying explained variance in multilevel models: An integrative framework for defining r-squared measures. *Psychological Methods*, 24(3), 309.

- Sollberger, B., Rebe, R., & Eckstein, D. (2003). Musical chords as affective priming context in a word-evaluation task. *Music Perception: An Interdisciplinary Journal*, 20(3), 263–282.
- Steinbeis, N., & Koelsch, S. (2011). Affective priming effects of musical sounds on the processing of word meaning. *Journal of Cognitive Neuroscience*, 23(3), 604–621.
- Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. *Teaching of Psychology*, 44(1), 24–31.
- Tramo, M. J., Cariani, P. A., Delgutte, B., & Braida, L. D. (2001). Neurobiological foundations for the theory of harmony in Western tonal music. *Annals of the New York Academy of Sciences*, 930(1), 92–116.
- Warriner, A. B., Kuperman, V., & Brysbaert, M. (2013). Norms of valence, arousal, and dominance for 13,915 english lemmas. *Behavior Research Methods*, 45(4), 1191–1207.
- Whelan, R. (2008). Effective analysis of reaction time data. *The Psychological Record*, 58(3), 475–482.
- Wilkinson, L. (1999). Statistical methods in psychology journals: Guidelines and explanations. *American Psychologist*, 54(8), 594.
- Winkielman, P., & Cacioppo, J. T. (2001). Mind at ease puts a smile on the face: Psychophysiological evidence that processing facilitation elicits positive affect. *Journal of Personality and Social Psychology*, 81(6), 989–1000.
- Zentner, M., & Eerola, T. (2010). Self-report measures and models. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 187–221). Oxford University Press Oxford, UK.
- Zentner, M. R., & Kagan, J. (1996). Perception of music by infants. *Nature*, 383(6595), 29.

- Arthurs, Y., Beeston, A. V., & Timmers, R. (2018). Perception of isolated chords: Examining frequency of occurrence, instrumental timbre, acoustic descriptors and musical training. *Psychology of Music*, 46(5), 662–681.
- Baguley, T. (2009). Standardized or simple effect size: What should be reported? *British Journal of Psychology*, 100(3), 603–617.
- Blair, K., Richell, R., Mitchell, D., Leonard, A., Morton, J., & Blair, R. (2006). They know the words, but not the music: Affective and semantic priming in individuals with psychopathy. *Biological Psychology*, 73(2), 114–123.
- Bowling, D. L., & Purves, D. (2015). A biological rationale for musical consonance. *Proceedings of the National Academy of Sciences*, 112(36), 11155–11160.
- Bowling, D. L., Purves, D., & Gill, K. Z. (2018). Vocal similarity predicts the relative attraction of musical chords. *Proceedings of the National Academy of Sciences*, 115(1), 216–221.
- Costa, M. (2013). Effects of mode, consonance, and register in visual and word-evaluation affective priming experiments. *Psychology of Music*, 41(6), 713–728.
- Costa, M., Ricci Bitti, P. E., & Bonfiglioli, L. (2000). Psychological connotations of harmonic musical intervals. *Psychology of Music*, 28(1), 4–22.
- Delacre, M., Lakens, D., & Leys, C. (2017). Why psychologists should by default use Welch's t-test instead of Student's t-test with unequal group sizes. *International Review of Social Psychology*, 30, 92–101.
- Fazio, R. H. (2001). On the automatic activation of associated evaluations: An overview. *Cognition & Emotion*, 15(2), 115–141.
- Harrison, P., & Pearce, M. (2019). Instantaneous consonance in the perception and

- composition of Western music. *PsyArXiv Preprints*. Retrieved from <https://doi.org/10.31234/osf.io/6jsug>
- Hermans, D., De Houwer, J., & Eelen, P. (2001). A time course analysis of the affective priming effect. *Cognition & Emotion*, 15(2), 143–165.
- Herring, D. R., White, K. R., Jabeen, L. N., Hinojos, M., Terrazas, G., Reyes, S. M., ... Crites Jr, S. L. (2013). On the automatic activation of attitudes: A quarter century of evaluative priming research. *Psychological Bulletin*, 139(5), 1062–1089.
- Hilbig, B. E. (2016). Reaction time effects in lab-versus web-based research: Experimental evidence. *Behavior Research Methods*, 48(4), 1718–1724.
- Hutchinson, W., & Knopoff, L. (1978). The acoustic component of Western consonance. *Interface*, 7(1), 1–29.
- Hutchinson, W., & Knopoff, L. (1979). The significance of the acoustic component of consonance in Western triads. *Journal of Musicological Research*, 3(1-2), 5–22.
- Kameoka, A., & Kuriyagawa, M. (1969). Consonance theory part I: Consonance of dyads. *The Journal of the Acoustical Society of America*, 45(6), 1451–1459.
- Krantz, G., Merker, B., & Madison, G. (2004). Subjective reactions to musical intervals assessed by rating scales. In *Proceedings of The Eighth International Conference on Music Perception and Cognition* (Vol. 5). Evanston, IL: Northwestern University.
- Lahdelma, I., & Eerola, T. (2016a). Mild dissonance preferred over consonance in single chord perception. *I-Perception*, 7(3), 1–21.
- Lahdelma, I., & Eerola, T. (2016b). Single chords convey distinct emotional qualities to both naive and expert listeners. *Psychology of Music*, 44(1), 37–54.

- Liu, X., Xu, Y., Alter, K., & Tuomainen, J. (2018). Emotional connotations of musical instrument timbre in comparison with emotional speech prosody: Evidence from acoustics and event-related potentials. *Frontiers in Psychology, 9*, 737.
- Maher, T. F. (1980). A rigorous test of the proposition that musical intervals have different psychological effects. *The American Journal of Psychology, 93*, 309–327.
- Malmberg, C. F. (1918). The perception of consonance and dissonance. *Psychological Monographs, 25*(2), 93–133.
- Oelmann, H., & Laeng, B. (2009). The emotional meaning of harmonic intervals. *Cognitive Processing, 10*(2), 113–131.
- Palan, S., & Schitter, C. (2018). Prolific.ac—a subject pool for online experiments. *Journal of Behavioral and Experimental Finance, 17*, 22–27.
- Peer, E., Brandimarte, L., Samat, S., & Acquisti, A. (2017). Beyond the Turk: Alternative platforms for crowdsourcing behavioral research. *Journal of Experimental Social Psychology, 70*, 153–163.
- Plomp, R., & Levelt, W. J. M. (1965). Tonal consonance and critical bandwidth. *The Journal of the Acoustical Society of America, 38*(4), 548–560.
- Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin, 114*(3), 510–532.
- Rights, J. D., & Sterba, S. K. (2019). Quantifying explained variance in multilevel models: An integrative framework for defining r-squared measures. *Psychological Methods, 24*(3), 309.
- Sollberger, B., Rebe, R., & Eckstein, D. (2003). Musical chords as affective priming context in a word-evaluation task. *Music Perception: An Interdisciplinary Journal, 20*(3),

263–282.

Steinbeis, N., & Koelsch, S. (2011). Affective priming effects of musical sounds on the processing of word meaning. *Journal of Cognitive Neuroscience*, *23*(3), 604–621.

Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. *Teaching of Psychology*, *44*(1), 24–31.

Tramo, M. J., Cariani, P. A., Delgutte, B., & Braida, L. D. (2001). Neurobiological foundations for the theory of harmony in Western tonal music. *Annals of the New York Academy of Sciences*, *930*(1), 92–116.

Warriner, A. B., Kuperman, V., & Brysbaert, M. (2013). Norms of valence, arousal, and dominance for 13,915 english lemmas. *Behavior Research Methods*, *45*(4), 1191–1207.

Whelan, R. (2008). Effective analysis of reaction time data. *The Psychological Record*, *58*(3), 475–482.

Wilkinson, L. (1999). Statistical methods in psychology journals: Guidelines and explanations. *American Psychologist*, *54*(8), 594.

Winkielman, P., & Cacioppo, J. T. (2001). Mind at ease puts a smile on the face: Psychophysiological evidence that processing facilitation elicits positive affect. *Journal of Personality and Social Psychology*, *81*(6), 989–1000.

Zentner, M., & Eerola, T. (2010). Self-report measures and models. In P. Juslin & J. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 187–221). Oxford University Press Oxford, UK.

Zentner, M. R., & Kagan, J. (1996). Perception of music by infants. *Nature*, *383*(6595), 29.